Automatic circuit tester

A digital computer saves time and money in production-line checkout of digital logic modules

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The job of production testing has become much too sophisticated for patch-panel and wired-chassis techniques, except on a limited basis. Combining transistors, diodes, and resistors and capacitors into operational circuits which are then tested as integral packages has multiplied the problems of control. The small computer is the logical tool of the system designer for production testing. The computer test system concept does more than automate production testing; it adds procedures impossible to carry out previously to present test capabilities.

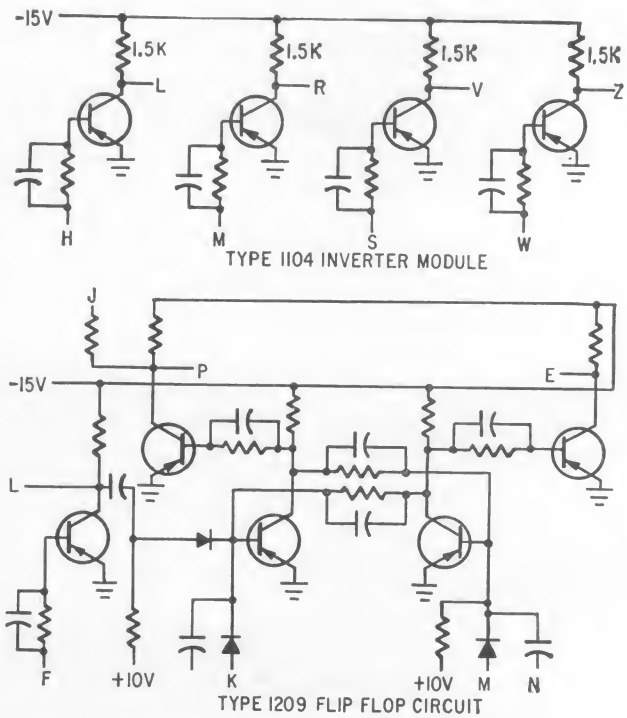
Comparison

The figure at the right shows some typical circuits being tested by computer control. The flip-flop and inverter are tested for logic functions, saturation voltages, fan-in, fan-out, rise time, fall time, delay time, and sensitivity to signal and noise. The circuits are complex and manual testing is costly and slow.

The table below compares costs and speeds of testing the inverter manually and automatically.

	Manual test	Automatic test
Time	10 minutes	10 seconds
Operator rate and overhead	\$7.00/hour	\$7.00/hour
Cost/module	62.5 cents	1.4 cents
Rate/operator	50/day	3,200/day

Assuming only 50% utilization time on the automatic tester, the savings per day total \$980. Flip-flops, which are more complicated and require one-half to one hour in manual testing, can be tested automatically at savings of about \$2,400 per day. A more realistic cost comparison considers capital investment and overhead. Manual test setups consist of a good oscilloscope, voltmeter, power supplies and pulse generators. The cost for this hardware is generally from \$4,000 to \$10,000. In addition, a separate switching box must be designed and built for each type of module tested.



Typical logic circuits to be tested

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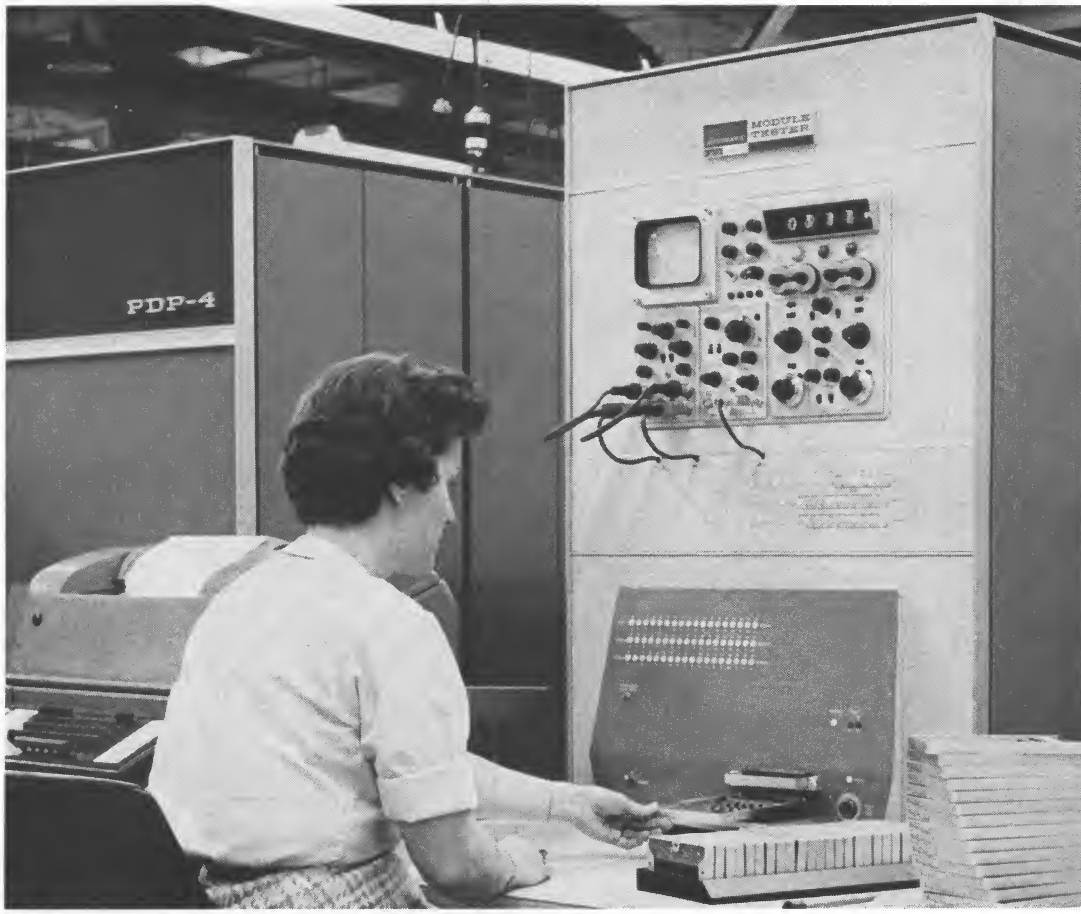

Production-line testing of digital logic circuits, showing tray of adapters, one for each type of module to be tested. A PDP-5 is used in the testing system described.

Each box costs about $2,000.

A typical manual-test facility consisting of 24 stations represents an investment of from $48,000 to $80,000. The total output of such a test area with 24 operators is only 600 modules per day. By comparison, an automatic test facility will cost from $70,000 to $100,000 ($30,000 of this is for a PDP-5 computer) and its total output is 3,200 modules per day with only one operator.

Automatic test system

The automatic module test system consists of three groups of equipment (see photo above):

- The central controller is a PDP-5 digital computer. It commands the testing functions, evaluates the readings, and controls the output devices.
- A test console which contains all of the necessary power supplies and analog metering.
- Input-output devices, consisting of a paper tape reader, a teleprinter, and a paper tape punch.

When the Digital Equipment Corp. built a system for its own use, the PDP-5 computer had not yet been developed, so the system was based on the PDP-4. With the advent of the PDP-5, it became possible to design a lower-priced testing system, and it is this system that is described here. Both the PDP-4 and PDP-5 emphasize flexibility in input-output functions. This flexibility permits the computers to service many types of peripheral equipment, and to accept and feed out data at rates varying from one signal every several seconds to 125,000 a second in a PDP-4, or 166,000 a second in the PDP-5. These figures relate to computer cycle time, which is the time required to read information from memory and rewrite information back into memory. For the PDP-4, cycle time is eight microseconds; for the PDP-5, six microseconds.

The basic test operation consists of typing the module number on the teleprinter keyboard, plugging in the module to be tested, and plugging in an adapter. The system then starts the test sequence. If the test is successful, the tester prints out an OK about six seconds later. If the module fails the test, the tester stops the system and types out complete information on the failure.

In the printout (at left on p. 78) type 1104 four-stage inverters were tested. The first entry, typed by the operator, caused the appropriate test parameters to be brought from computer core memory and started the testing. The next five entries typed out by the computer indicated five modules successfully tested. The sixth module failed the load test, and the tester typed out the name of the test, the measurement limits (1,400 to 1,600 ohms), the actual reading (710 ohms), the input pin (H), the output pin (L), and the word, reject. The second reject to occur was due to a slow transistor tied to

```
1104      MODEL NUMBER SELECTED
          BY TYPING ON KEYBOARD
 1104 OK
 1104 OK
 1104 OK
 1104 OK
 1104 OK        ALLOWABLE TEST LIMITS
 1104
LOAD TEST 1400 TO 1600 OHMS
    710   H  L REJECT
 1104 OK              OUTPUT PIN
 1104 OK              INPUT PIN
 1104 OK              ACTUAL READING
 1104 OK
 1104 OK
 1104 OK
 1104 OK
 1104
RISE        FALL
 40          100 NS
 60          108       S  V REJECT
 1104 OK
 1104 OK
 1104 OK
 1104 OK
```

▲ **Production test printout,** showing two rejects

Data-sheet printout, with complete logging ▶ of test results for one inverter module

```
 1104
LOAD TEST 1400 TO 1600 OHMS
   1475   W   Z
   1490   S   V
   1505   M   R
   1475   H   L
LWR LEV TEST -3.2 TO -3.7 VOLTS
-3.4        W   Z
-3.4        S   V
-3.4        M   R
-3.4        H   L
VCE TEST 0 TO 130 MV
     70     W   Z
     90     S   V
     90     M   R
     80     H   L
RISE        FALL
 40          100 NS
 36          38         W   Z
 24          63         S   V
 23          61         M   R
 22          59         H   L
 OK
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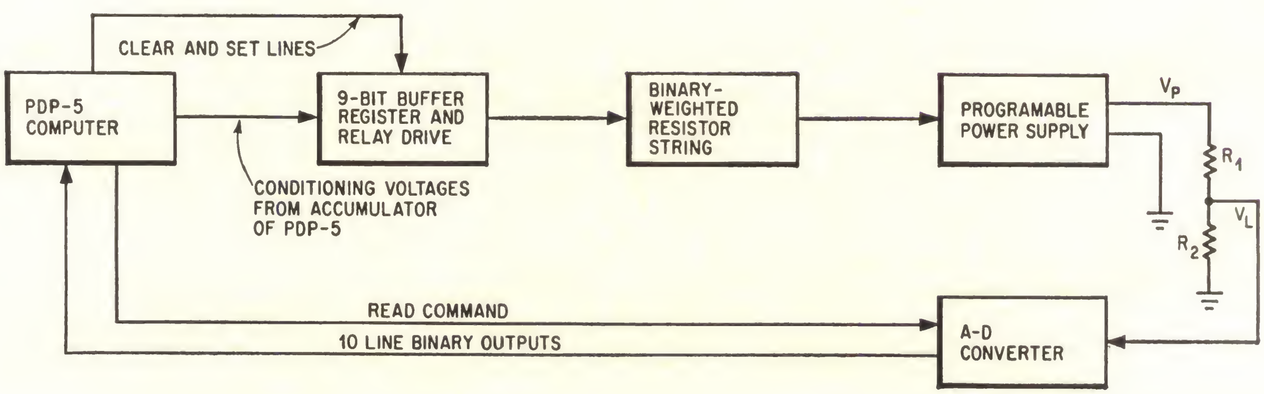
▼ **Measurement circuit** for testing components and circuits



pin V, shown near the bottom of the printout.

The data printed out simplifies repair of a circuit. In the first case, the load resistor tied to pin L was replaced. In the second case, the transistor tied to pin V was replaced with one having acceptable rise and fall times.

Automatic failure analysis

Printout of test results on go, no-go testing makes repairs to modules easy; manual testing relies on the operator to read a meter, lights or oscilloscope. He must make 60 to 100 decisions to evaluate defective components, based on the combinations of test results.

Manual systems, of course, have no data-logging capability other than operator, pencil and paper. Other semiautomatic data-logging systems must be built, with a specific data-logging function in mind. With a computer, data logging is simple. The computer already is equipped to communicate with typewriters or card punches. The printout (at right on p. 78) shows the complete data presented by the computer for a tested 1104 module.

The headings can be changed easily to fit any situation. For example, the heading "LWR LEV TEST" can be made to read "VOFF" by modifying the information in the computer memory. Both headings refer to the collector voltage for a turned-off pnp transistor, but one may be preferred to the other in certain circumstances. In all cases, the test limits and actual test results are shown as well as the input pins, output pins and the test result.

To provide flexibility of programing of test conditions and test limits, the computer program can be modified by typing the new numbers into the proper locations in the memory. For example, voltage limits are stored numbers in the memory and the actual readings are compared to these stored numbers for go, no-go decisions. If it were necessary to change 3.7 volts to 3.5 volts, the operator would find the memory location of the 3.7 and type in the number 3.5.

For power supply flexibility, computers allow complete freedom as to the sequencing and delay between applied voltages (a feature often necessary to avoid destructive testing). The changes require only the modification of the stored program by typing the sequence of supplies required and the proper delays between applied voltages.

Frequently, certain inaccuracies which cannot be easily accounted for in any other test method can be modified by the computer. For example, in the measurement of the delay time of a flip-flop, the reading of the digital scope did not include the 100-nanosecond pulse width of the generator. This constant of 100 nsec was added to the readings received by taking advantage of the computer's add function.

Computer communications for testing

Computer applications to testing result from the use of programable stimuli such as power supplies (digital-to-analog devices), and in analog-to-digital converters. In the simplified sample circuit for measuring any device where a stimulus and a measurement are required (see figure at bottom of p. 78), a computer controls a programable power supply, and a measuring device, in this case an a-d converter.

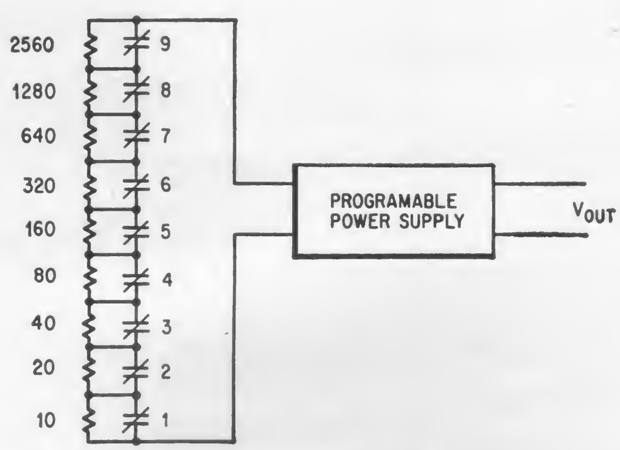
Readings from the a-d converter are fed back to the computer for storage and comparison. In this kind of test set-up, it is possible to test, under controlled conditions, such devices as diodes, transistors, resistors, relays, and circuit packages and modules containing these components. Measurements of resistance, current, and voltage are made so that components can be tested rapidly and economically.

In the output process, information to be transferred is taken from the computer memory on command and put into an accumulator—a temporary storage register in the computer. This information appears in binary form. The computer transfers this information into a buffer register, also in binary form and in the same order it appeared in the accumulator. By selecting a particular output command, any one of a group of registers is loaded with the binary information from the accumulator. When this operation is completed, the power supply produces an analog equivalent of the digital voltage. A typical technique for programing a power supply is shown in the figure below.

The output of the power supply depends on the amount of resistance in the programing string. Relays 1 through 9 are opened as needed by a nine-bit storage register.

Inputs from the accumulator are fed to eight capacitor-diode gates that control eight flip-flops. When these gate inputs are at zero volts and a command pulse also appears at the eight gates, a pulse is fed through the enabled gates, setting certain of the flip-flops to one state. Each flip-flop in turn operates a relay driver. A clear pulse is provided to set all the flip-flops to the zero state.

The binary-weighted output of the programable



Technique for programing a power supply, with a binary-weighted resistor string controlled by normally-closed relay contacts. Output voltage is KR_{in}, where K equals 1V/(100 ohms).

power supply can be any value from 0 to 51.1 volts in 0.1-volt steps. The individual bit values are:

Bit number	Voltage
1	0.1
2	0.2
3	0.4
4	0.8
5	1.6
6	3.2
7	6.4
8	12.8
9	25.6

For a reading of 0 volts, all bits of the register contain zeros. With ones in all bits, the voltage reading would be 51.1. To program 25.8 volts, the binary number would be 010 000 001; that is, 0.2 plus 25.6. To program 1.1 volts, the binary number would be 110 100 000; that is, 0.1 plus 0.2 plus 0.8.

The routine used by the computer to load the register is a simple two-instruction process:

Instruction	Meaning
LAC 1000	Load the accumulator with the number in memory location 1000.
IOT 6754	Clear and load the ones from the accumulator into the buffer register.

To carry out these instructions, the computer transfers the binary number from memory location 1000 to the buffer register. To produce the 25.8 volts cited above from the programable power supply, the number in location 1000 would be 010 000 001.

After the programed voltage, V_P, is generated the analog voltage, V_L, must be measured. To do this, the computer issues a read command which causes the a-d converter, by successive approximations, to convert the reading to a binary number. For example if $V_L = 1.52$ volts, the binary number generated by the a-d converter is 010 011 000, assuming a value of 0.01 volt for the least significant bit; that is, $1.28 + 0.16 + 0.08 = 1.52$.

This information is now ready for the computer. A third command, "enter data from a-d," is issued and the 010 011 000 (1.52 volts) is transferred to the accumulator of the computer, destroying the previous information in the accumulator.

A typical routine used to program a voltage and measure is shown at left below.

Circuit testing

By expanding the number of buffer registers and with proper programing, the tests for a large number of modules or components can be stored simultaneously in the computer core memory. Information is loaded into the memory from paper tape. The memory contains instructions for testing the 1104, as well as 20 to 30 other module types. To select the testing sequence for 1104, simply type in "1104." The computer then compares this number to a stored table, which lists all modules that can be tested. If the number is mistyped or does not exist in the memory table, the computer types back a "no," indicating error in selection.

On correct selection, the operator need only load the test socket with the module to be tested, push the test button, and the test procedure is carried out automatically. The module goes through a load-resistance test, V_{CE} (collector-to-emitter terminal voltage) test, lower-level test (off-voltage), and rise and fall time tests, by expanding the concept of in-out transfer.

The programable power supply is programed at 2.8 volts, and the computer controls the switching. This voltage is applied in sequence to each of the bases of the 1104 inverter pins H, M, S and W, as shown on page 78 at top left. The voltage is measured by sequentially connecting the a-d converter through similar switching to pins L, R, V and Z. The a-d converter measurements are then fed into the computer and compared against stored limits.

The computer can now take action based on test results, and print a readout. Similar techniques are used to measure lower levels and load resistance with different input voltages and test limits.

A-c rise and fall measurements are made by programing a digital-readout sampling oscilloscope and a pulse and sync generator. The digitized reading from the sampling oscilloscope is similarly fed into the computer memory for evaluation. This system depends on the analog readings that have been digitized rather than on a go, no-go type of comparator. Digitized readings allow for data-logging and easy modification of test limits and test conditions.

Computer routine

Inst. No.	Instruction	Remarks
1	LAC 5000	Load the accumulator with the contents of memory location 5000 (2.58 v binary)
2	6754	Store 010 000 001 in programmable power supply buffer (PPS now goes to 2.58 v)
3	6755	Convert a-d. A-D converter reads V_{out} and converts it to binary 010 011 000. (1.52 volts)
4	6756	Transfer the a-d converter binary output to the accumulator
5	DAC 5001	Store the contents of the accumulator in memory location 5001 for further reference
6	Jm s Compare	Compare a-d reading with minimum and maximum stored limits
7	END	End of test routine

The author

Kenneth Wakeen is chief engineer at the Nexus Research Laboratory. He designed the automatic circuit tester while he was manager of production engineering at the Digital Equipment Corp. He is married, has five children, and his hobbies are oil painting and golf.